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Transmission design for the XL-RIS-aided massive MIMO system with visibility regions

Key words: Reconfigurable intelligent surface; Massive multi-input multi-output (MIMO); Two-timescale transmission scheme; Visibility regions.

Luchu LI
E-mail: 220240860@seu.edu.cn
ORCID: https://orcid.org/0009-0006-4977-1254

Motivation

1. Although the advantages of the reconfigurable intelligent surface (RIS) have been demonstrated in the aforementioned studies, most of them were built on the assumption of estimating instantaneous CSI in each channel coherent interval.
2. In the most of the aforementioned studies, the focus was on channel estimating and spatial non-stationary effects caused by XL-MIMO systems.

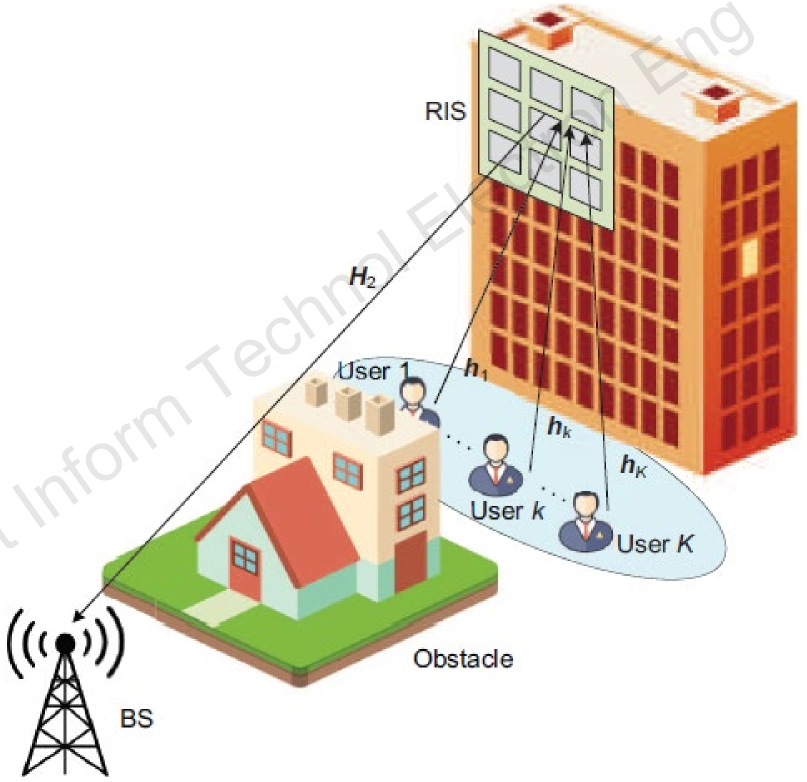
	Instantaneous CSI	Two-timescale CSI
Number of pilots	Proportional to the number of RIS elements	Proportional to the number of users
Beamforming calculations	Performed frequently within each channel coherent interval	The update rate is much lower than the instantaneous CSI

Main idea

1. By employing the low-complexity maximal ratio-combining (MRC) detector at the BS, we derived a closed-form expression of the uplink achievable rate under the correlated Rician channel model in the presence of visibility regions (VRs). We also analyzed VRs' impact and assessed how they help reduce computational complexity.
2. We formulated the problem of maximizing the minimum user rate with statistical channel state information (CSI) and proposed an effective algorithm for designing the phase shifts of the extremely large-scale (XL) RIS based on accelerated gradient ascent.
3. We provided simulation results about various important parameters to reveal the properties and benefits of integrating XL-RIS into massive MIMO networks.

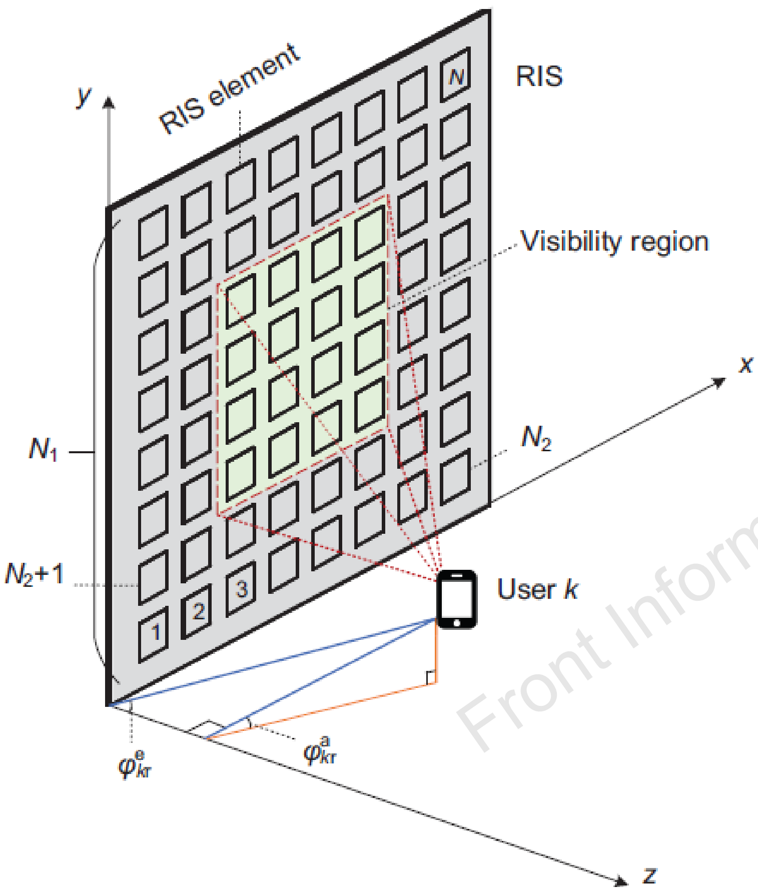
1) System model

- A typical XL-RIS-aided massive MIMO communication system with one BS, one XL-RIS, and *K* single-antenna users.
- The RIS is connected to the BS through a dedicated transmission link.



An XL-RIS-aided massive MIMO system

2) VR model



The 3D geometry of an XL-RIS, in the presence of VR.

- We use VRs to capture spatially non-stationary fading characteristics.

- For the spatial non-stationary characteristics brought about by the expansion of the XL-RIS array, we use the RIS correlation matrix and the visibility indicator matrix to capture the characteristics.

3) User-achievable rate analysis

$$\mathrm{RATE}_{\mathrm{VR},k} \approx \mathbb{E}\left\{\log_2\left[\frac{pE_{\mathrm{VR},k}^{\mathrm{signal}}(\boldsymbol{\Phi})}{p\sum_{i=1,i\neq k}^{K} I_{\mathrm{VR},ki}(\boldsymbol{\Phi})+\sigma^2 E_{\mathrm{VR},k}^{\mathrm{noise}}(\boldsymbol{\Phi})}+1\right]\right\}$$

- Since *K* users share the same RIS-BS channel, the BS-to-user cascading channel is coupled and not Gaussian, which is difficult to calculate.

- By using the matrix compression theory, we can reduce redundancy and complexity.

4) Gradient algorithm

Algorithm 1 Gradient algorithm

```
Randomly initialize θ_0 and set i = 0, e_0 = 1, x_{-1} = θ_0
while 1 do
    Calculate f'_VR(θ_i)
    Obtain the step size κ_i based on the backtracking line search
    x_i = θ_i + κ_i f'_VR(θ_i)
    e_{i+1} = (1 + sqrt(4e_i^2 + 1))/2
    θ_{i+1} = x_i + (e_i − 1)(x_i − x_{i−1})/e_{i+1}
    if f_VR(θ_{i+1}) − f_VR(θ_i) < 10^{-4} then
        θ* = θ_{i+1}, break
    end if
    i = i + 1
end while
```

- The performance is mainly dependent on the step size
- The parameter selection is more robust
- Only use real variables
- Can avoid suboptimal projection operations
- Faster calculations

Major results

The influence of VRs

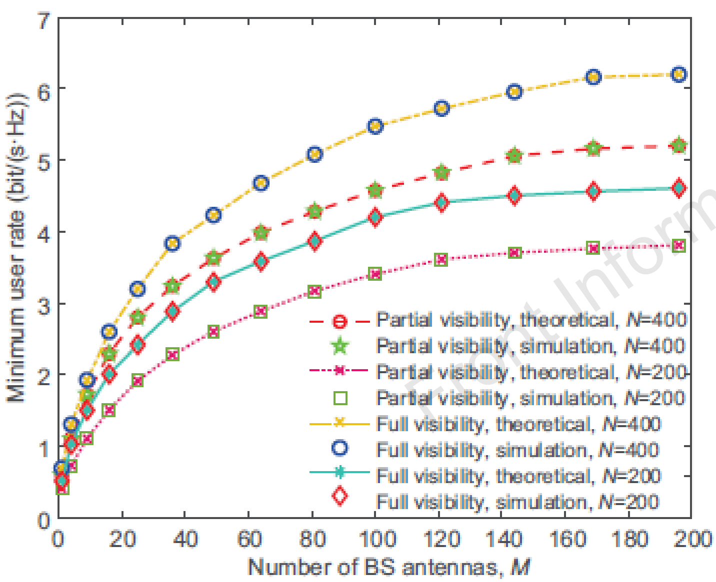


Fig. 3 Minimum user rate versus number of BS antennas (BS: base station)

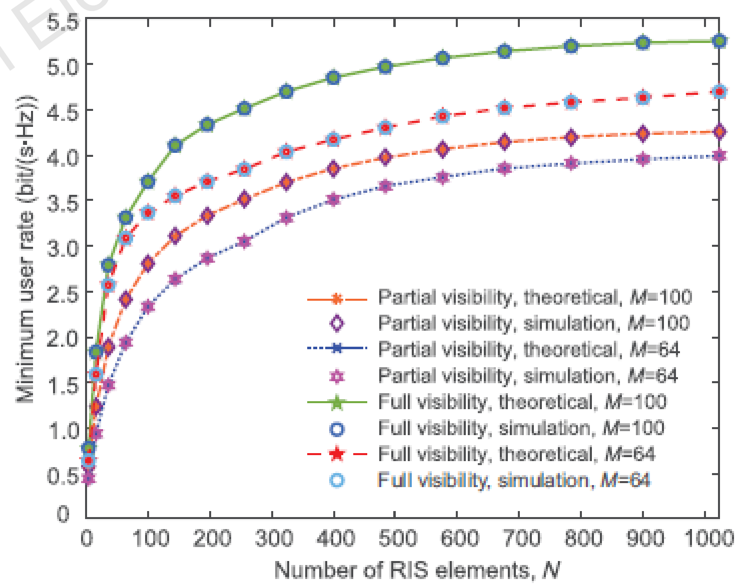


Fig. 4 Minimum user rate versus number of RIS elements (RIS: reconfigurable intelligent surface)

Major results

The influence of overlapping VRs and RIS element spacing

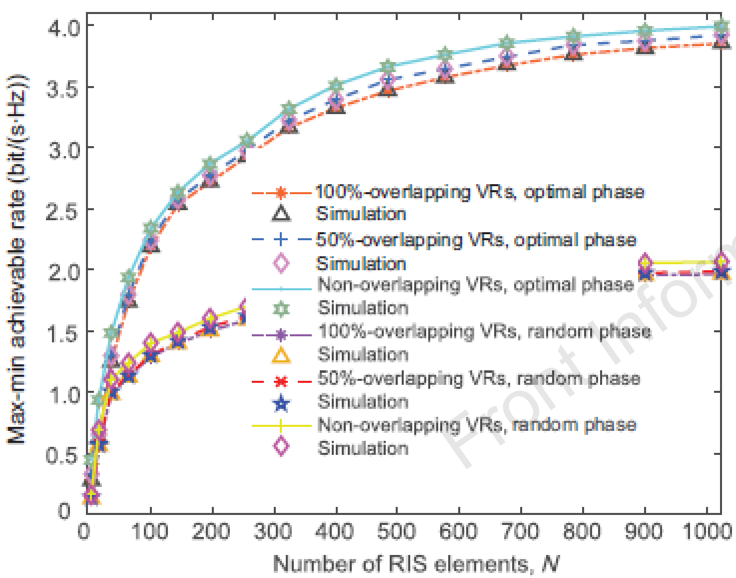


Fig. 8 Max-min achievable rate versus N for overlapping and non-overlapping VRs (VRs: visibility regions)

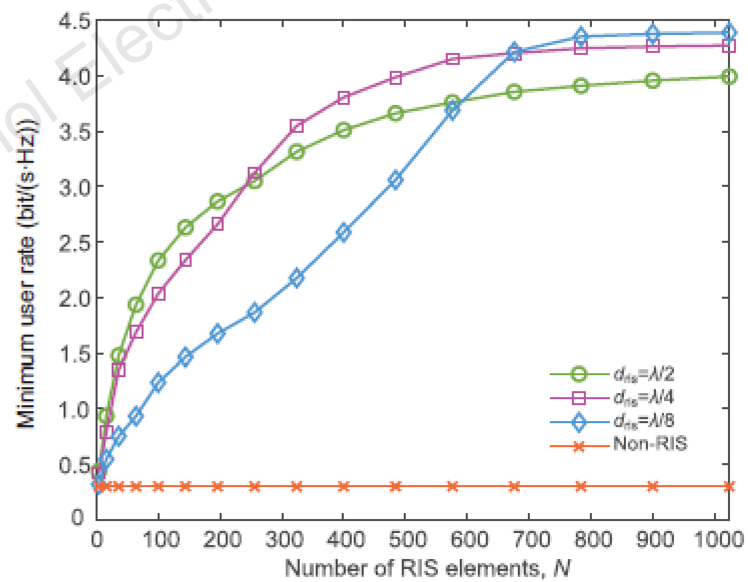


Fig. 9 Max-min achievable rate versus N for different values of the RIS element spacing $d_{\rm ris}$ (RIS: reconfigurable intelligent surface)

Conclusions

1. We considered a spatially-correlated channel model in the presence of VRs. A closed-form expression of the achievable user rate was derived and the optimization problem was clarified.

2. We analyzed the impact of the VR of the RIS on system complexity and simplified the user rate expression.

3. We proposed a gradient algorithm different from the GA and validated the potential of applying it to the phase shift optimization problem.

4. We conducted simulations and analysis about XL-RIS-aided massive MIMO systems, and the impact of VRs on system performance was verified from different perspectives.

About the Authors

Luchu LI (first author): Currently pursuing a Master’s degree at School of Information Science and Engineering, Southeast University.

Cunhua PAN (corresponding author): National Mobile Communications Research Laboratory, Young Chief Professor and Ph.D. Supervisor in the School of Information Science and Engineering at Southeast University.